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DAMAGE APPRAISAL AND PHEROMONE TRAPPING STUDIES FOR THE BLACK ARMY CUTWORM IN BRITISH COLUMBIA

BY
THOMAS F. MAHER*

FOREST RESOURCE DEVELOPMENT AGREEMENT

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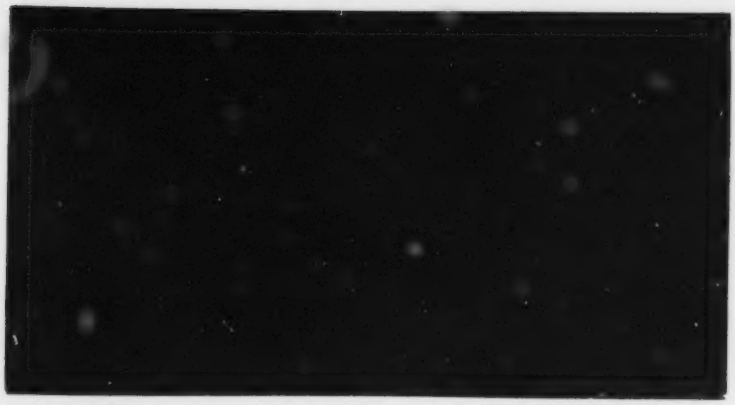

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1.0 INTRODUCTION

The black army cutworm(Actebia fennica Tauscher) is presently known to be widely distributed throughout the northern hemisphere (Clark and Carew 1985, Pulliainen 1963). Prior to 1964, black army cutworm(BAC) infestations in British Columbia were recorded only in agricultural situations(Allen and Wood 1973). Since that time, BAC populations have been identified in recently planted sites in the Prince Rupert, Prince George, Cariboo, Kamloops and Nelson Forest Regions(Humble et.al 1989). A map identifying all known collections of black army cutworm is contained in Appendix 1. Outbreaks generally occur where broadcast burning has been used for site preparation or following wildfires, as burned-over areas appear to be preferred locations for egg deposition by the immigrating adult moths(Phipps 1927, Ross and Ilnytzky 1977). Tree hosts of the BAC found to date include the spruces(Picea spp.), lodgepole pine(Pinus contorta), Douglas-fir(Pseudotsuga menziesii), western larch(Larix occidentalis) and aspen(Populus tremuloides). Other trees may also be favourable hosts if planted following fire.

The 1-year life cycle of the BAC has been described by Wood and Neilson(1956). The actual calendar dates of each life stage can vary from year to year; depending on weather conditions, geographical location, aspect and elevation. Emergence and flight of adult moths can occur from early July to late September. Oviposition takes place 2-5 weeks following emergence. The overwintering stage is presumed to be newly-hatched larvae, but no observations of this life stage have been made in B.C. Nocturnal larval feeding begins as soon as the snow cover has melted in early spring, but day-time feeding occurs when night temperatures are too low to permit larval activity. The larvae pass through six instars in a 5-6 week period before pupating about mid-June. The pupal stage lasts for 3-4 weeks when the next generation of adult moths emerge to disperse.

Extreme fluctuations of population levels are characteristic of the BAC. One or two years after a prescribed or wild fire, many thousands of larvae can suddenly appear and severely defoliate all vegetation, including natural or planted seedlings. Larval distribution and subsequent damage is patchy throughout an infestation. Outbreaks generally last for 1 to 2 years, when large populations may be found spotted over an extensive geographical area; followed by a period of varying length when populations are extremely low. The larvae feed primarily on succulent herbaceous plants, and damage to seedlings generally occurs when the level of preferred herbaceous material is insufficient to satisfy larval feeding demands. Therefore, the degree of seedling damage is dependent on a complex interaction between larval population level and date of emergence, as well the species, phenological stage of development and density of herbaceous vegetation.

Until the present time it has been impossible to predict where BAC infestations would occur, the level of seedling damage which would be sustained, or to predict the short and long-term impacts of the damage. Consequently, foresters have had to deal with BAC outbreaks by arbitrarily delaying planting schedules, using pesticide applications or undertaking decision-making on a crisis basis; without adequate knowledge of these important factors.

2.0 PROJECT OBJECTIVES

The lack of adequate data on the short and long-term impacts of BAC damage(in relation to seedling mortality and height growth) and the capability of a recently developed pheromone trapping system to predict subsequent BAC larval populations were the primary research topics addressed in this study. Due to the complex interaction of available herbaceous vegetation and larval density with seedling defoliation, data on vegetation preference and larval stages were also collected in order to accomplish the following objectives:

1. Assessment of mortality losses and height growth reductions due to BAC defoliation and terminal bud damage.

2. Assessment of the influence of initial seedling height and time of planting in relation to defoliation upon rates of mortality and height growth losses.

3. Determination of seedling susceptibility of different species to BAC related defoliation and damage.

4. Correlation of pheromone trap catches with subsequent larval populations and seedling damage.

5. Assessment of the association between vegetation defoliation during larval feeding and final level of seedling defoliation.

6. Development of guidelines to assist foresters in minimizing the losses to this regeneration pest.

3.0 MATERIALS AND METHODS

3.1 Damage Appraisal Plots

Plots were established within BAC outbreaks and an attempt was made to collect data on at least 15 seedlings within a given cell consisting of several variables. These variables included 4 initial height classes, 4 seedling species, 5 levels of defoliation and 2 planting times in relation to time of defoliation. The latter consisted of seedlings planted at the same time as larval feeding(called 'current') and seedlings planted a year prior to defoliation(called 'post'), as previous data had indicated that post-defoliated seedlings incurred lower levels of mortality(Unger and Stewart 1986).

In some cases there were not sufficient seedlings available to fill a given cell, and subsequent mortality losses resulted in the sample size between cells varying considerably. In the case of larch, no outbreaks occurred during planting operations during this study, therefore a few seedlings(74) were planted within a small outbreak in 1989 in order to obtain at least some data.

The circular damage appraisal(DA) plots consisted of an inner portion(3.99 m radius) within which data was recorded on all seedlings, and an outer portion consisting of the nearest twelve(12) seedlings. All plots were referenced to painted, 1.5 metre aluminum point-of-commencement stakes, and all tie lines between plots were heavily flagged to aid in relocation during subsequent remeasurements. After ten circular plots were established for a given species and planting time, tabular summaries were prepared to identify missing portions of the desired data base. Subsequently, additional plots were established until a minimum of fifteen(15) seedlings(or all available seedlings) in each defoliation level and height class had been recorded. The following data were recorded for each plot:

A. Plot data
- location
- defoliation time(current or post)
- block and plot number
- date
- distance and bearing to next plot

B. Seedling data
- defoliation level
- terminal bud damage
- initial height
- bark feeding incidence
- no. of lateral buds damaged
- species
- comments

Remeasurements consisted of mortality losses and height growth during the previous growing season. All dead seedlings were carefully excavated and examined for cause of mortality. Seedlings that were obviously poorly-planted(squashed plugs, J-roots or buried in rotten wood etc.) were recorded as indirect mortality losses due to the effects of BAC defoliation and damage combined with poor planting quality. Otherwise the mortality was attributed to BAC defoliation alone. Additional seedlings which suffered mortality from elk trampling or browsing were deleted from the analysis. Height growth in each year was measured as the length of the terminal shoot and added to the original tree height to obtain the new tree height. The height growth of terminally damaged trees were sometimes recorded as a negative quantity; in seedlings where the adventitious bud which assumed apical dominance emerged from below the original terminal bud, indicating that the total height of the seedling was shorter than when it was planted, even after one or two growing seasons.

3.2 Vegetation Appraisal Plots

Collection of vegetative data consisted of the establishment of 55 circular vegetation damage(VD) plots within the Golden Forest District. Additional VD plots were not established in 1989 because of the rapid decline of BAC populations. The VD plots consisted of 3.99 m radius circular plots as described for the DA plots. The following data were recorded 3 times at 2-week intervals for each plot:

- location
- block and plot number
- date
- total vegetative cover
- defoliation level on seedlings
- defoliation level of herbaceous cover by species
- percentage cover of each herbaceous species
- stage of phenological development of each species
- stage of larval development
- distance and bearing to next plot

Larval collections were made during each remeasurement and the specimens boiled and placed in a 95% ethanol solution for later determination of instar development.

3.3 Pheromone Trapping

The trapping system utilized non-sticky, green 'Multi-Pher I' traps(Bio-Contôle Services, Ste. Foy, Quebec) baited with 1000 mg of a two-component pheromone(Raylo Chemicals Ltd., Edmonton, Alberta). In 1987, a total of 46 traps were placed in the Invermere, Clearwater and Golden Forest Districts. The trapping level was intensified in 1988 to include 85 traps placed under this research study and 44 traps placed by the Ministry of Forests, within the Golden, Revelstoke and McBride Forest Districts. All 1987 traps and a sub-sample of the 1988 traps were emptied every 2 weeks to determine flight period duration.

3.4 Data Analysis

Data bases for mortality losses were statistically tested using a two-tailed t-test for percentages(Fairchild 1959). The height growth data were examined by general linear model Analysis of Variance(ANOVA). No transformations were possible because of the negative growth due to terminal damage. When significant difference were detected in the ANOVA, the means were analyzed using Duncan's multiple range test.

A sub-sample of the larval development collections were examined with an ocular micrometer and instar phases were based on the distribution of head capsule widths using the instar bounds determined by Forestry Canada(courtesy of L. Humble, 1989 unpub. data).

The pheromone trapping samples were sorted and male BAC moths counted volumetrically. A summary of trap catches in relation to subsequent larval populations was prepared.

4.0 RESULTS AND DISCUSSION

Initial data were recorded for 5067 seedlings in 228 plots(Table 1), of which 3809 seedlings survived for final growth measurements at the conclusion of the study period. Losses were due to browsing, planting and cutworm mortality. There were substantial variations in both site and elevation between the study sites(Appendix 2), a factor which is believed to have strongly influenced the responses of seedlings to defoliation and damage by the BAC.

The percentage of seedlings exhibiting terminal/lateral bud damage or bark feeding by data base is presented in Table 2. It can be seen that there was a large variablity in the severity of seedling damage between the data bases, particularly in the levels of terminal damage. There was an obvious progression in the levels of terminal damage, bark feeding and percentage of damaged lateral buds as defoliation level increased. Records from all data bases were sorted into initial height classes, but there were no differences in damage levels between these classes.

4.1 Mortality Losses

Mortality losses were divided into three groups, those due to the effect of defoliation only in well-planted trees(BAC-alone); from the interaction of defoliation and poor planting(BAC/planting) and total mortality which combined the two mortality factors.

Total mortality levels between initial height classes were not different, nor were groupings of low and high levels of bark feeding or damaged buds. Therefore, these factors were deleted from the subsequent mortality analyses. The majority(greater than 90%) of mortality occurred in the first year following defoliation, indicating that the seedlings usually succumb either in the first growing season or during the winter following defoliation.

Significant differences in total mortality were only observed in defoliation classes greater than 60%(Table 3), indicating that seedlings are quite resilient and able to survive considerable defoliation before succumbing. When the defoliation level was greater than 60%, 7 of the 10 data bases had significantly greater total mortality than the control, 5 of which were near Golden. The only factor common to all the Golden data bases was a prolonged period of moisture stress during the post-defoliation period. Langstrom and Hellqvist(1989) presented data showing up to 75% mortality in spruce and pine seedlings following partial girdling by artificial methods, which could simulate the effect of severe moisture stress because water translocation to the actively growing regions was reduced. Therefore, the hypothesis was developed that the additional stress due to post-defoliation drought dramatically reduced the ability of the seedlings to survive in the Golden data sets.

TABLE 1. DESCRIPTION OF DAMAGE APPRAISAL DATA BASES.

LOCATION	SPECIES	TIMING	ABBREVIATION	NO. OF PLOTS		1 ORIGINAL SAMPLE		2 RESIDUAL SAMPLE	
				CIRCULAR	LINE	Control	Cutworm	Control	Cutworm
Clearwater	Pine	Current	CLWPLCUR	20	5	81	265	45	185
Invermere	Pine	Current	INVPLCUR	19	8	134	522	86	331
	Fir	Current	INVDFCUR	21	3	93	331	45	179
	Spruce	Current	INVSPCUR	28	11	205	751	172	635
Golden	Pine	Current	GLDPLCUR	10	1	32	241	22	150
	Pine	Post	GLDPLPOST	21	9	116	411	106	384
	Fir	Current	GLDDFCUR	15	6	114	377	103	268
	Fir	Post	GLDDFPOST	15	6	76	455	63	305
	Larch	Current	GLDLWCUR	0	1	10	68	10	64
	Larch	Post	GLDLWPOST	24	5	184	601	169	487

1 Number of seedlings on which original height and defoliation data were taken.

2 Number of seedlings suitable for measurement at end of study period after browsing, planting and mortality losses.

TABLE 2. SAMPLE SIZE, INITIAL SEEDLING HEIGHT AND PERCENTAGE OF SEEDLINGS EXHIBITING TERMINAL/LATERAL BUD DAMAGE OR BARK FEEDING BY DEFOLIATION CLASS.

DEFOLIATION CLASS	PARAMETERS	CLW PL CUR	INV PL CUR	GLD PL CUR	GLD PL POST	INV DF CUR	GLD DF CUR	GLD DF POST	GLD LW CUR	GLD LW POST	INV SP CUR
CONTROL	Residual n	45	86	22	106	45	103	63	10	169	172
	Initial Height	11.0	13.5	19.4	24.6	16.7	24.2	25.1	30.0	38.9	21.3
1 - 30 %	Residual n	68	52	40	115	85	108	32	18	160	170
	Initial Height	11.1	14.0	20.4	22.9	16.5	24.6	24.4	28.9	40.4	22.0
	Without TD	100%	75%	100%	100%	33%	69%	22%	45%	71%	71%
	With TD	0%	25%	0%	0%	67%	31%	78%	55%	29%	29%
	Bark Feeding	12%	8%	0%	63%	5%	4%	6%	0%	4%	14%
	Damaged Buds	N/A	N/A	N/A	N/A	27%	9%	31%	N/A	N/A	22%
31 - 60 %	Residual n	60	63	29	101	50	70	16	19	113	152
	Initial Height	12.7	14.8	18.8	23.5	17.5	24.3	24.7	28.1	36.9	21.9
	Without TD	100%	70%	100%	100%	16%	74%	0%	47%	69%	25%
	With TD	0%	30%	0%	0%	84%	26%	100%	53%	31%	75%
	Bark Feeding	15%	21%	3%	64%	12%	3%	0%	0%	4%	13%
	Damaged Buds	N/A	N/A	N/A	N/A	38%	14%	62%	N/A	N/A	56%
61 - 99 %	Residual n	50	112	46	80	42	49	61	15	107	157
	Initial Height	11.8	15.6	17.8	24.3	17.2	25.1	25.2	27.2	37.6	22.0
	Without TD	88%	77%	87%	92%	14%	49%	0%	47%	54%	9%
	With TD	12%	23%	13%	8%	86%	51%	100%	53%	46%	91%
	Bark Feeding	26%	47%	2%	81%	12%	8%	0%	6%	7%	28%
	Damaged Buds	N/A	N/A	N/A	N/A	43%	35%	74%	N/A	N/A	68%
100 %	Residual n	46	104	33	86	0	41	192	12	107	156
	Initial Height	11.6	15.2	18.6	23.4	-	23.9	26.0	26.0	36.5	22.4
	Without TD	87%	60%	67%	51%	-	22%	0%	50%	5%	5%
	With TD	13%	40%	33%	49%	-	78%	100%	50%	95%	95%
	Bark Feeding	65%	57%	9%	69%	-	24%	13%	90%	84%	45%
	Damaged Buds	N/A	N/A	N/A	N/A	-	75%	100%	N/A	N/A	78%

N/A - Indicates that lodgepole pine does not possess lateral buds at this early stage of development and that lateral buds on larch are producing current foliage, therefore the damage level is represented by the defoliation class.

TD - terminal damage

TABLE 3. TOTAL PERCENTAGE MORTALITY OF SEEDLINGS DAMAGED BY THE BLACK ARMY CUTWORM AS COMPARED TO CONTROL SEEDLINGS.

LOCATION SPECIES TIMING	CONTROL	PERCENT DEFOLIATION 1 - 30 %		31 - 60 %		61 - 99 %		100 %		> 60% DEFOLIATION
	TREES	NTD	TD	NTD	TD	NTD	TD	NTD	TD	NTD + TD
CLWPLCUR	7.4 a	5.7 a	N/A	4.9 a	N/A	6.9 a	0.0 a	9.7 a	47.0 b	11.4 b
INVPLCUR	7.5 a	11.1 a	5.9 a	1.6 a	9.4 a	7.4 a	15.5 a	8.8 a	25.0 b	12.7 a
GLDPLCUR	3.1 a	14.5 a	N/A	9.5 a	16.7 a	14.2 a	22.2 a	44.2 b	27.8 b	27.4 b
GLDPLPOST	6.9 a	3.4 a	N/A	1.9 a	N/A	1.3 a	0.0 a	10.2 a	13.0 a	6.9 a
INVDFCUR	8.6 a	9.2 a	5.9 a	0.0 a	6.4 a	7.7 a	5.6 a	N/A	21.4 a	7.8 a
GLDDFCUR	5.3 a	7.1 a	5.3 a	1.8 a	4.5 a	14.7 a	26.3 b	37.5 b	53.9 b	39.0 b
GLDDFPOST	2.6 a	0.0 a	0.0 a	N/A	0.0 a	N/A	0.0 a	N/A	29.0 b	21.9 b
GLDLWCUR	0.0 a	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	12.9 b
GLDLWPOST	1.1 a	0.8 a	0.0 a	0.0 a	0.0 a	0.0 a	6.9 b	12.5 b	39.3 b	24.5 b
INVSPCUR	7.3 a	6.3 a	1.8 a	0.0 a	5.6 a	22.2 b	6.5 a	9.1 b	20.5 b	14.6 b

N/A - Indicates that insufficient data available(n < 5) within a terminal damage class or that the total sample size is less than 30 within a defoliation class.

Means followed by the same letter within each data base(row) are not significantly different (t-test, p < .05).

The severity of an outbreak varies considerably from one situation to another(i.e. there is no 'average'). Due to the wide variablity of residual sample sizes of individual defoliation classes between data bases and the knowledge that these data bases do not reflect the normal distribution of defoliation levels during an outbreak, comparisons of overall mortality between locations would be misleading. Concern about seedling mortality arises when high populations are present and the seedlings become severely defoliated. Therefore, the following descriptions and tests were done using only the seedlings which had incurred greater than 60% defoliation(called severely defoliated). In other words, these analyses represent the 'worst case' scenario in which all of the seedlings within a plantation incur greater than 60% defoliation.

Of special interest is the low levels(9% maximum) of BAC-alone mortality in severely defoliated seedlings, and only in the larch post data set was the level of BAC-alone mortality significantly different from planting mortality in the control seedlings(Figs. 1-3). In 7 of the 10 data bases, BAC-alone mortality was lower than than the controls. These results are consistent with data from Sweden(Langstrom and Hellqvist 1989), which showed mortality losses of 5%(pine) and 10%(spruce) in seedlings which were artificially decapitated or defoliated.

It appears that when the effect of additional stress due to poor planting was combined with BAC defoliation and terminal damage, mortality levels rose substantially. When both factors were operating, mortality was greater than the controls in all data bases except Douglas-fir current and pine post, 4 of which were significantly different(Fig. 3). Langstrom and Hellqvist(1989) found that severe defoliation of spruce and pine seedlings significantly reduced root growth. The reduction of new root development due to defoliation in a poorly planted seedling or one that is experiencing drought places the seedling in double jeopardy in terms of survival. This may explain why there is such a rapid increase in mortality when other factors come into play in conjunction with defoliation.

Total mortality was higher than the controls in 8 of the 10 data sets, of which 6 were significantly different(Table 3, Figs. 1-3). The highest levels of total mortality of occurred in the Douglas-fir(39%) and pine(27%) seedlings defoliated current with planting near Golden.

A comparison of the mortality levels between species and locations of seedlings defoliated current with planting indicated that there was no differences in BAC-alone mortality among the 3 areas, nor among the levels of planting mortality in the control seedlings(Fig. 4, Table 4). Both BAC/planting and total mortality were greatest in the Douglas-fir and pine data sets near Golden, while the other data sets were similar. Douglas-fir mortality in seedlings defoliated current with planting was significantly higher than pine or larch near Golden possibly due to post-defoliation drought, as near Invermere the Douglas-fir mortality was significantly lower than spruce or pine. When defoliation occurred one year after planting, larch incurred the most total mortality, followed by Douglas-fir and then pine(Fig. 5, Table 4). The occurrence of almost 25% mortality in larch defoliated 1 year after planting was not anticipated, as it was expected that due to the deciduous habit of this

FIG. 1 MORTALITY LEVELS AT GREATER THAN 60% DEFOLIATION-CLEARWATER F.D.
Stars show significant differences

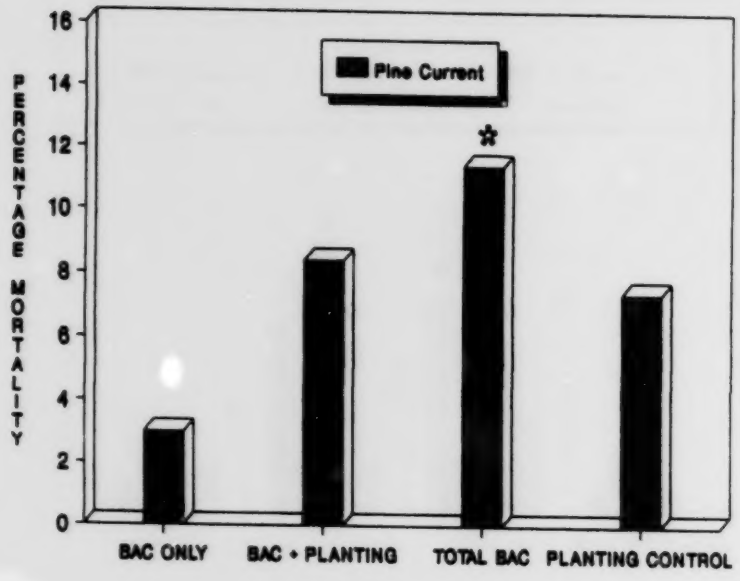

FIG. 2 MORTALITY LEVELS AT GREATER THAN 60% DEFOLIATION - INVERMERE F.D.
Stars show significant differences

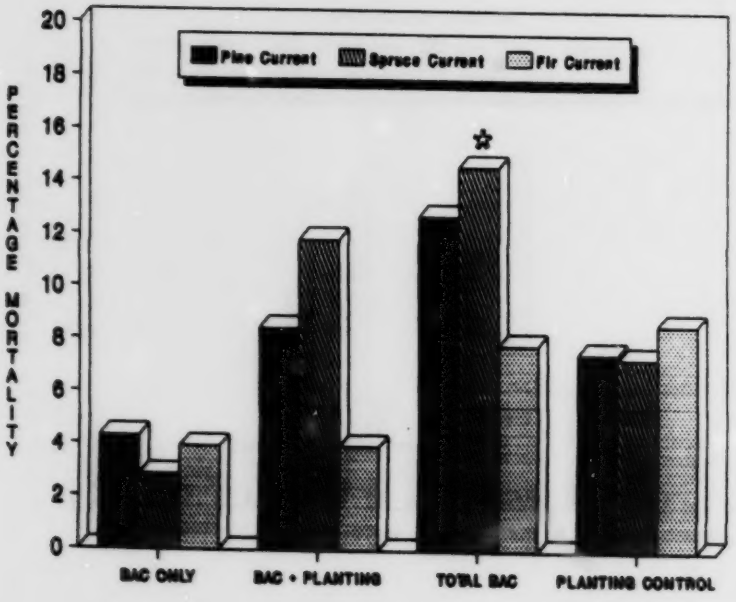

FIG. 3 MORTALITY LEVELS AT GREATER THAN 60% DEFOLIATION - GOLDEN F.D.
Stars show significant differences

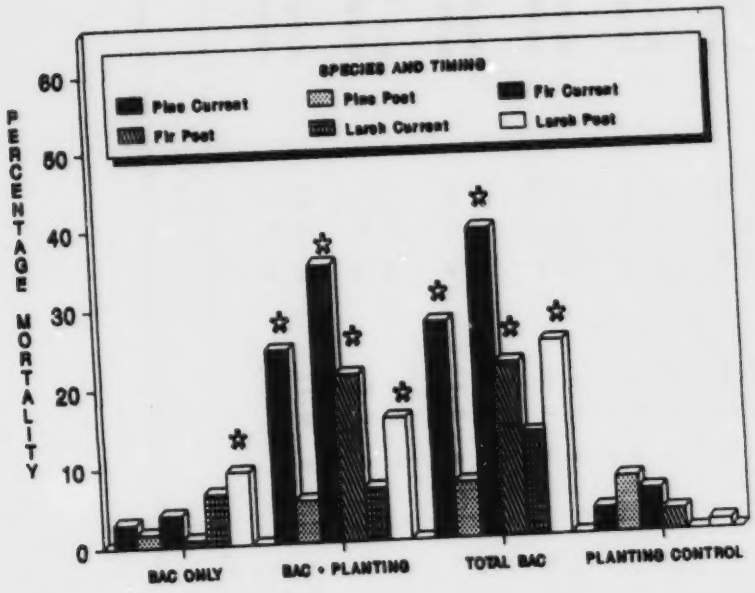

FIG. 4 MORTALITY LEVELS AMONG LOCATIONS
CURRENT DEFOLIATION MORE THAN 60%

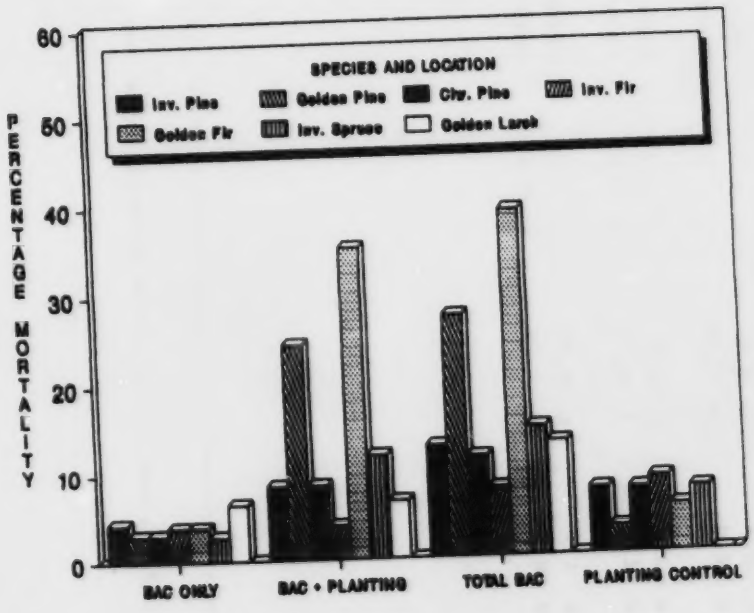

TABLE 4. COMPARISON OF PERCENTAGE MORTALITY BETWEEN SPECIES WITHIM THE SAME LOCATION FOR SEEDLINGS WITH GREATER THAN 60% DEFOLIATION.

LOCATION SPECIES TIMING	TOTAL BAC MORTALITY	BAC + PLANTING MORTALITY	BAC - ALONE MORTALITY	LOCATION SPECIES TIMING	TOTAL BAC MORTALITY	BAC + PLANTING MORTALITY	BAC - ALONE MORTALITY
GLDPLCUR	27.4 a	24.4 a	3.0 a	GLDPLPOST	6.9 a	5.3 a	1.6 a
GLDDFCUR	39.0 b	35.1 b	3.9 a	GLDDFPOST	21.9 b	21.1 b	0.8 a
GLDPLCUR	27.4 a	24.4 a	3.0 a	GLDPLPOST	6.9 a	5.3 a	1.6 a
GLDLWCUR	12.9 a	6.5 b	6.4 a	GLDLWPOST	24.5 b	15.4 b	9.1 b
GLDLWCUR	12.9 a	6.5 a	6.4 a	GLDLWPOST	24.5 a	15.4 a	9.1 a
GLDDFCUR	39.0 b	35.1 b	3.9 a	GLDDFPOST	21.9 a	21.1 b	0.8 b
INVPLCUR	12.7 a	8.4 a	4.3 a				
INVSPCUR	14.6 a	11.8 a	2.8 a				
INVPLCUR	12.7 a	8.4 a	4.3 a				
INVDFCUR	7.8 a	3.9 a	3.9 a				
INVSPCUR	14.6 a	11.8 a	2.8 a				
INVDFCUR	7.8 b	3.9 b	3.9 a				

Means followed by the same letter within in each grouping are not significantly different(t-test, $p < .05$).

species the survival rate following defoliation would be high. Again, the reduction of root growth due to defoliation followed by post-defoliation drought is a possible explanation.

Of critical importance are the differences in mortality levels within a species when defoliation current with planting is compared to defoliation 1 year after planting(Fig. 6). In the three available data sets from Golden, there were no significant differences between current and post defoliated seedlings in BAC-alone mortality. The level of total mortality was significantly lower in post-defoliated seedlings except in larch. But due to the experimental planting of the larch current data set and the large differences in sample size(74 for current, 656 for post), it is believed that this species would have also shown the same differences had the two data sets been more comparable. These differences were also present in BAC/planting mortality.

4.2 Height Growth Losses

Providing that seedlings survive BAC defoliation/damage, the impact of defoliation and terminal damage upon subsequent height growth was studied. The impact of terminal damage was most pronounced in the first year; as the mean height growth for terminally damaged seedlings in most defoliation classes was significantly different from the control seedlings(Table 5). The greatest impact appears to have been incurred by Douglas-fir. Non-terminally damaged seedlings showed much smaller height growth losses than those with terminal damage, with the effects increasing with the degree of defoliation(Table 5). At greater than 60% defoliation, half of the data sets without terminal damage had significantly less growth than the control trees.

By the end of the second growing season seedlings showed smaller differences in height growth as compared to the first year in all defoliation and terminal damage classes. The difference in height growth was still significantly different in most of the defoliation classes greater than 60%(Table 6). The obvious anomaly in Clearwater pine current which shows the non-terminally damaged trees having greater height growth rates after 2 years is due to the fact that sheep were used for brush control in the defoliated portions of the block during all 3 years of re-measurements, but not in the undefoliated portion of the block which contained the control seedlings. Therefore, the defoliated seedlings experienced substantially less vegetative competition during the recovery period.

Third year height growth data was only available from the 4 data sets which were initiated in 1987(Table 7). There were no significant differences between controls and severely defoliated but non-terminally damaged seedlings in all cases except spruce, but growth rates were still 9-39% smaller. Severely defoliated and terminally damaged seedlings at the time of planting in Invermere still showed differences of 20-59%. This means that severely defoliated seedlings had not fully recovered after their rates of height growth after 3 years, regardless of the occurrence of terminal damage.

FIG. 5 COMPARISON OF MORTALITY LEVELS
DEFOLIATION-1 YEAR AFTER PLANTING

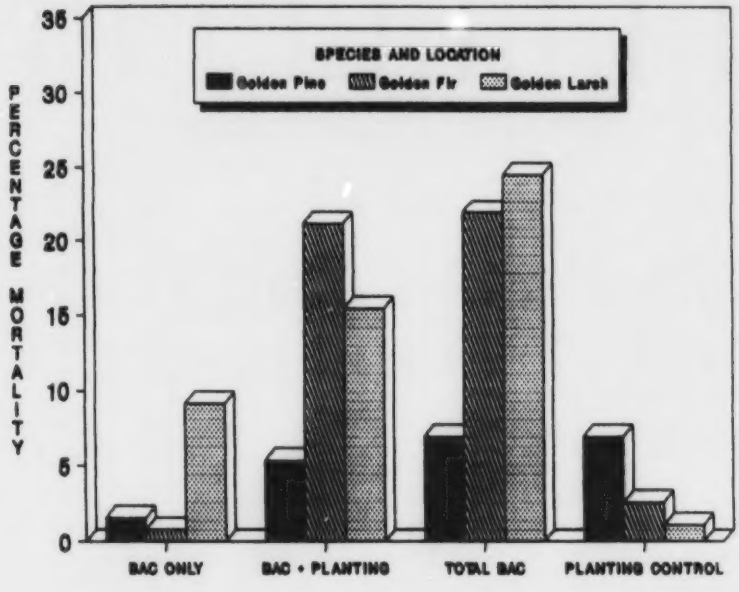

FIG. 6 COMPARISON OF MORTALITY BETWEEN
CURRENT AND POST DEFOLIATION-GOLDEN F.D.
Stars show significant differences

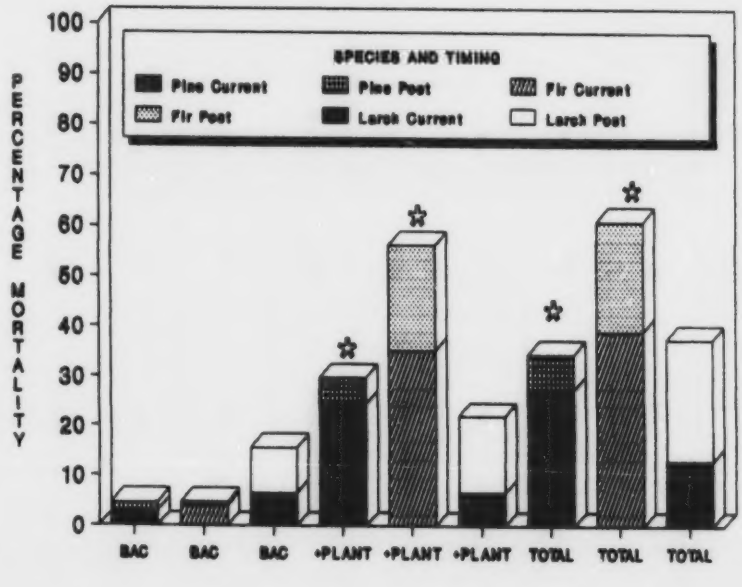

TABLE 5. COMPARISON OF MEAN HEIGHT GROWTH(cm) IN THE FIRST YEAR FOLLOWING DEFOLIATION BY THE BLACK ARMY CUTWORM.

LOCATION SPECIES TIMING	CONTROL TREES	1 - 30 % NTD	1 - 30 % TD	31 - 60 % NTD	31 - 60 % TD	61 - 99 % NTD	61 - 99 % TD	100 % NTD	100 % TD	> 60% DEFOLIATION % DIFFERENCE FROM CONTROL NTD	> 60% DEFOLIATION % DIFFERENCE FROM CONTROL TD	> 60% DEFOLIATION % DIFFERENCE FROM CONTROL ALL
CLWPLCUR	9.4 b	8.7 b	N/A	9.3 b	N/A	8.3 b	1.6 a	5.9 c	1.3 a	24	84	32
INVPLCUR	6.5 c	4.9 bc	0.7 b	5.7 bc	-1.5 a	4.4 b	-1.3 a	4.1 b	-1.6 a	34	123	61
GLDPLCUR	4.9 ab	5.6 b	N/A	4.8 ab	N/A	4.9 ab	3.3 a	4.4 ab	1.6 c	4	55	14
GLDPLPOST	19.8 d	16.1 c	N/A	13.2 bc	N/A	12.0 b	8.3 a	8.2 a	0.3 e	46	93	60
INVDFCUR	5.4 c	5.0 c	1.6 ab	5.6 c	-0.4 a	4.3 bc	-0.6 a	N/A	N/A	20	111	98
GLDDFCUR	6.2 d	5.5 d	4.8 cd	5.1 d	3.3 bc	4.9 d	2.8 ab	1.4 a	-3.1 e	37	108	82
GLDDFPOST	8.9 b	7.2 ab	8.0 ab	N/A	5.1 a	N/A	0.3 c	N/A	-7.9 d	N/A	166	166
GLDLWCUR	12.5 d	8.6 abc	5.8 a	12.0 cd	7.8 ab	10.6 bcd	7.1 ab	9.3 abcd	1.1 e	20	64	42
GLDLWPOST	47.6 f	37.5 de	42.4 ef	31.0 cd	27.8 bc	26.9 bc	18.1 a	21.4 ab	0.7 g	44	87	74
INVSPCUR	11.1 e	9.5 de	3.1 c	8.4 d	1.0 b	5.7 f	-0.2 ab	1.4 bc	-1.2 a	63	106	104

Means that are underscored by the same letter within each data base(row) are not significantly different, Duncan's multiple range test($p < .05$).

N/A - Indicates that insufficient data available (n < 5).

TD - terminal damage

NTD - no terminal damage

TABLE 6. COMPARISON OF MEAN HEIGHT GROWTH(cm) IN THE SECOND YEAR FOLLOWING DEFOLIATION BY THE BLACK ARMY CUTWORM.

LOCATION SPECIES TIMING	CONTROL	1 - 30 %		31 - 60 %		61 - 99 %		100 %		> 60% DEFOLIATION % DIFFERENCE FROM CONTROL		
	TREES	NTD	TD	NTD	TD	NTD	TD	NTD	TD	NTD	TD	ALL
CLWPLCUR	10.5 a	11.4 b	N/A	13.5 b	N/A	14.9 b	10.9 ab	11.9 b	7.2 a	+27	13	+21
INVPLCUR	9.0 de	10.0 e	5.5 bc	9.7 e	4.2 b	6.9 cd	3.3 ab	7.2 cd	1.7 a	22	74	38
GLDPLCUR	13.7 d	12.2 cd	N/A	9.6 bc	N/A	6.8 ab	5.2 a	4.4 a	4.5 a	56	66	58
GLDPLPOST	39.4 b	39.4 b	N/A	35.6 b	N/A	35.7 b	33.8 ab	28.7 a	14.9 c	16	56	28
INVDFCUR	5.9 a	6.1 a	4.6 a	4.4 a	4.7 a	4.9 a	4.5 a	N/A	N/A	17	24	22
GLDDFCUR	5.7 c	4.7 c	6.4 c	5.6 c	5.4 c	5.1 c	4.5 bc	2.7 a	3.0 ab	23	35	32
GLDDFPOST	16.5 b	16.9 b	14.5 b	N/A	9.6 a	N/A	7.3 a	N/A	8.2 a	N/A	52	52
GLDLWPOST	47.4 cde	52.7 bcd	41.9 e	48.6 bc	40.0 de	37.7 a	29.8 b	25.5 a	25.3 a	38	38	38
INVSPCUR	7.2 c	7.0 c	7.0 c	10.0 d	7.0 c	6.0 bc	5.4 bc	3.1 a	4.2 ab	32	33	33
GLDLWCUR	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Means that are underscored by the same letter within each data base(row) are not significantly different, Duncan's multiple range test, ($p < .05$).

N/A - Indicates that insufficient data available ($n < 5$), or data base was initiated in 1989.

TD - terminal damage

NTD - no terminal damage

TABLE 7. COMPARISON OF MEAN HEIGHT GROWTH(cm) IN THE THIRD YEAR FOLLOWING DEFOLIATION BY THE BLACK ARMY CUTWORM.

LOCATION / SPECIES / TIMING	CONTROL	1 - 30 %		31 - 60 %		61 - 99 %		100 %		> 60% DEFOLIATION % DIFFERENCE FROM CONTROL		
	TREES	NTD	TD	NTD	TD	NTD	TD	NTD	TD	NTD	TD	ALL
CLWPLCUR	21.6 a	22.8 a	N/A	24.6 a	N/A	27.7 a	22.0 a	25.4 a	21.6 a	+23	+1	+20
INWPLCUR	17.4 bcd	19.2 d	13.4 b	18.0 cd	6.7 a	13.8 bc	8.1 a	13.7 bc	6.5 a	21	59	31
INWDFCUR	10.0 a	9.9 a	9.8 a	10.1 a	8.3 a	9.1 a	8.0 a	N/A	N/A	9	20	11
INWSPCUR	11.2 de	10.5 cde	9.2 bcd	13.2 e	9.6 bcd	8.0 abcd	7.5 abc	4.8 a	6.9 ab	39	35	35

Means that are underscored by the same letter within each data base(row) are not significantly different, Duncan's multiple range test($p < .05$)

N/A - Indicates that insufficient data available ($n < 5$).

TD - terminal damage

NTD - no terminal damage

The annual height growth data has been summarized in Table 8 and graphed for each species, location and defoliation timing in Figs. 7-16. Two obvious trends in height growth appear consistently regardless of species, location or defoliation timing, with the exception of larch. The first trend is that the effect of defoliation only(i.e. non-terminally damaged trees) is small, as both growth rate(i.e. the slope of the line) and total height are almost equal in all years. Therefore, it appears that the pine, spruce, larch and Douglas-fir seedlings which did not suffer terminal damage were able to compensate for defoliation without losing much height growth. This result is consistent with data presented by Langstrom and Hellqvist(1989) as well as by Hoffman and Steiner(1965).

The second trend is that in pine and larch the rate of height growth is reduced in seedlings with terminal damage, so that they continue to fall farther and farther behind, at least up until the second and third year of this study(Figs. 8-12). With Douglas-fir and spruce, the rate of height growth is similar to the control trees but the actual increase is still less, so that these species are also falling behind, but at a slower rate(Figs. 13-16).

Langstrom and Hellqvist(1989) showed that significant differences in height growth continued for 4 years in pine but not in spruce. Therefore, we need to continue height growth remeasurements for all seedlings for a period of years to determine if full recovery of height will occur.

4.3 Overall Damage and Susceptibility

A summary of impacts of BAC defoliation/damage indicates that a large degree of variablity occurred(Table 9). BAC-alone mortality ranged from 0.8 - 9.1%. But when defoliation is combined with the additional stress from poor planting total mortality levels increased dramatically, ranging from 6.9 - 39.0%. Levels of terminal damage varied between species,locations and timing of defoliation. In order to compare the losses between all species, locations and timing; a ranking was assigned to BAC-alone mortality and percent difference in height growth. These two factors were chosen in an attempt to eliminate extraneous factors, in order to isolate the relative response of the seedlings to the stress caused solely by BAC defoliation and damage.

This primary damage rating(presented in order of increasing overall impact) showed that notwithstanding the deciduous habit of larch, this species incurred the greatest direct impacts from BAC defoliation, regardless of the timing of defolation. Douglas-fir seedlings defoliated 1 year after planting incurred the smallest impact in terms of mortality and height growth losses. No trends were observed due to the location of the data sets. A secondary damage rating which included the effects of poor planting combined with defoliation also did not show any trends.

TABLE 8. COMPARISON OF MEAN HEIGHT GROWTH(cm) FOLLOWING GREATER THAN 60% DEFOLIATION BY THE BLACK ARMY CUTWORM.

LOCATION SPECIES TIMING	YEAR 1			YEAR 2			YEAR 3			TOTAL GROWTH		
	CONTROL	NTD	TD	CONTROL	NTD	TD	CONTROL	NTD	TD	CONTROL	NTD	TD
CLMPLCUR	9.4 a	7.1 b	1.5 b	10.5 a	13.3 a	9.1 a	21.6 a	26.5 a	21.8 a	41.5 a	46.9 a	32.4 b
INVPLCUR	6.5 a	4.3 b	-1.5 b	9.0 a	7.0 b	2.3 b	17.4 a	13.8 b	7.1 b	32.9 a	25.1 b	7.9 b
INVDFCUR	5.4 a	4.3 a	-0.6 b	5.9 a	4.9 b	4.5 b	10.0 a	9.1 a	8.0 b	21.3 a	18.3 b	11.9 b
INVSPCUR	11.1 a	4.1 b	-0.7 b	7.2 a	4.9 b	4.8 b	11.2 a	6.8 b	7.2 b	29.5 a	15.8 b	11.3 b
GLDPLCUR	4.9 a	4.7 a	2.2 b	13.7 a	6.0 b	4.7 b	N/A	N/A	N/A	18.6 a	10.7 b	6.9 b
GLDPLPOST	19.8 a	10.6 b	1.3 b	39.4 a	33.1 b	17.3 b	N/A	N/A	N/A	59.2 a	43.7 b	18.6 b
GLDDFCUR	6.2 a	3.9 b	-0.5 b	5.7 a	4.4 b	3.7 b	N/A	N/A	N/A	11.9 a	8.3 b	3.2 b
GLDDFPOST	8.9 a	N/A	-5.9 b	16.5 a	N/A	8.0 b	N/A	N/A	N/A	25.4 a	N/A	2.1 b
GLDLWPOST	47.6 a	26.5 b	6.4 b	47.4 a	29.4 b	29.3 b	N/A	N/A	N/A	95.0 a	55.9 b	35.7 b
GLDLWCUR	12.5 a	10.0 b	4.5 b	N/A	N/A	N/A	N/A	N/A	N/A	12.5 a	10.0 b	4.5 b

Means that are underscored by the same letter within each data base(row) are not significantly different, different, Duncan's multiple range test($p < .05$).

N/A - Indicates that remeasurements were not taken as data base was initiated in 1988 or 1989.

TD - terminal damage

FIG. 7 CLEARWATER PINE GROWTH - GREATER THAN 60% DEFOLIATION AT PLANTING

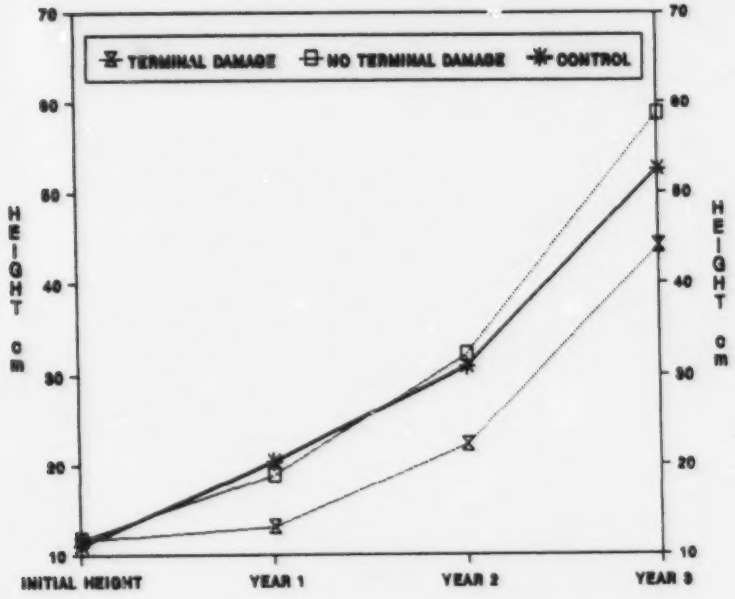

FIG. 8 INVERMERE PINE GROWTH - GREATER THAN 60% DEFOLIATION AT PLANTING

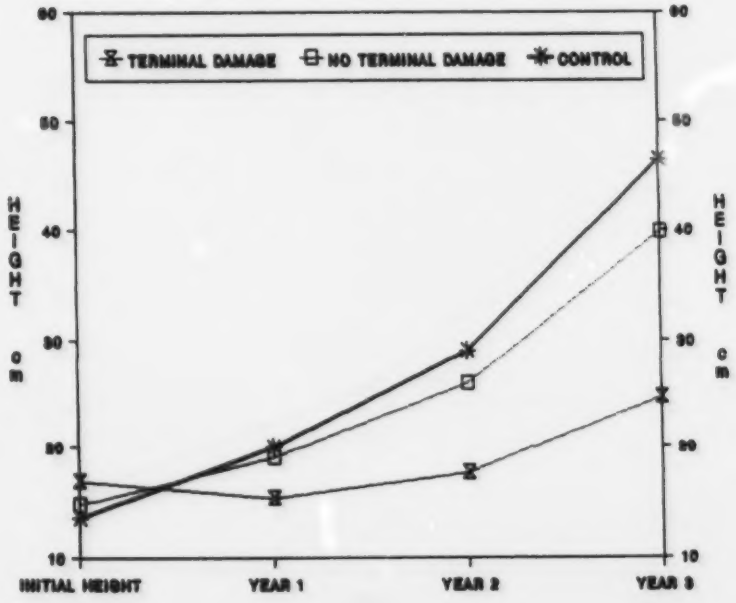

FIG. 9 GOLDEN PINE GROWTH - GREATER THAN 60% DEFOLIATION AT PLANTING

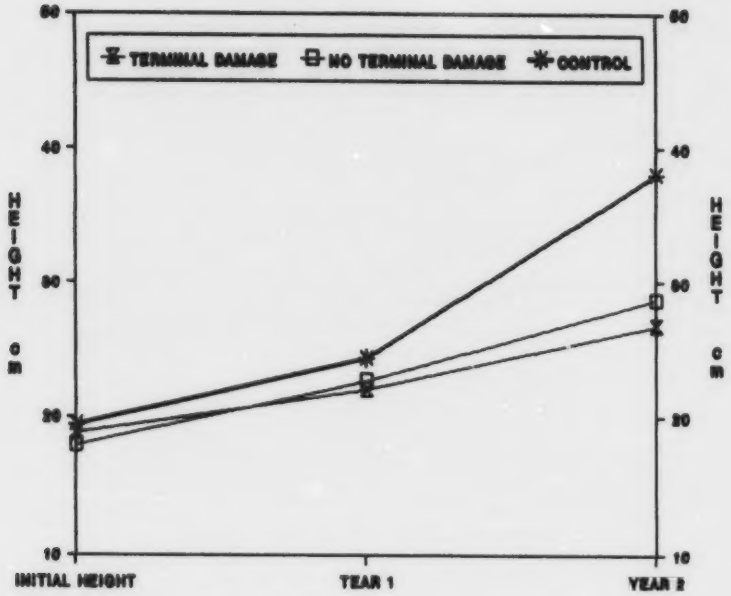

FIG. 10 GOLDEN PINE GROWTH - MORE THAN 60% DEFOLIATION POST PLANTING

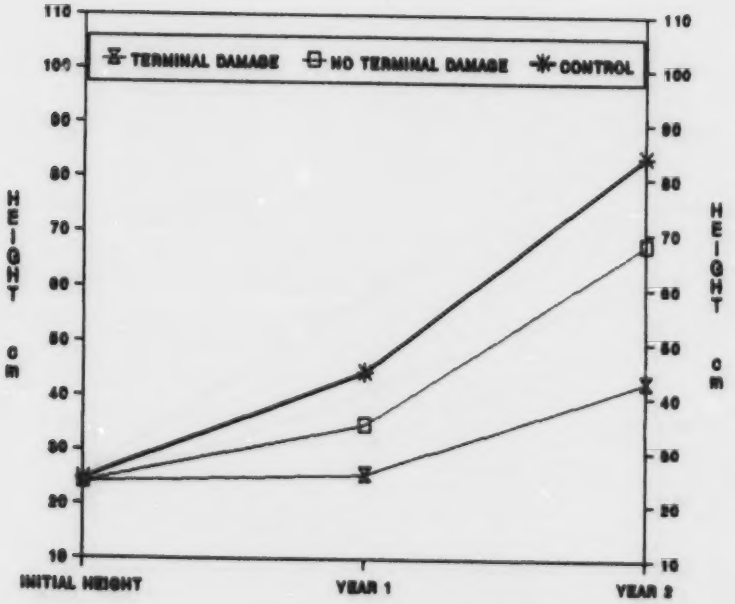

FIG. 11 GOLDEN LARCH GROWTH - GREATER THAN 60% DEFOLIATION AT PLANTING

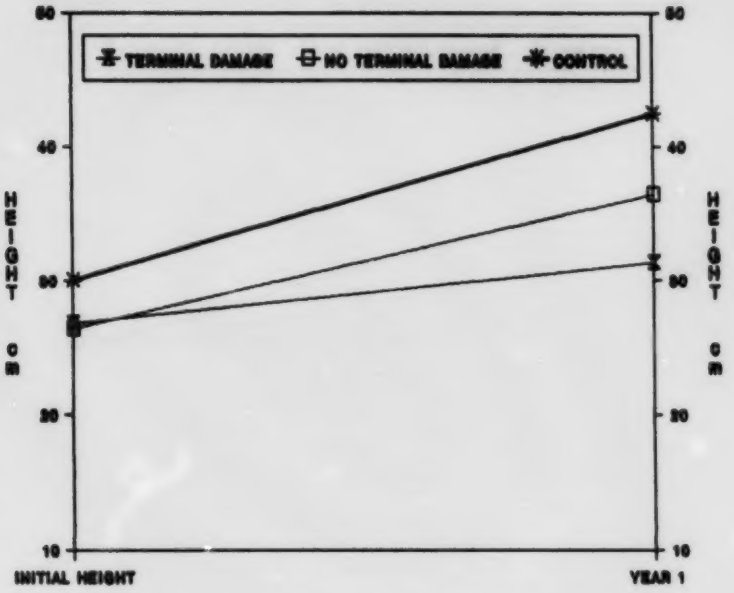

FIG. 12 GOLDEN LARCH GROWTH - GREATER THAN 60% DEFOLIATION POST PLANTING

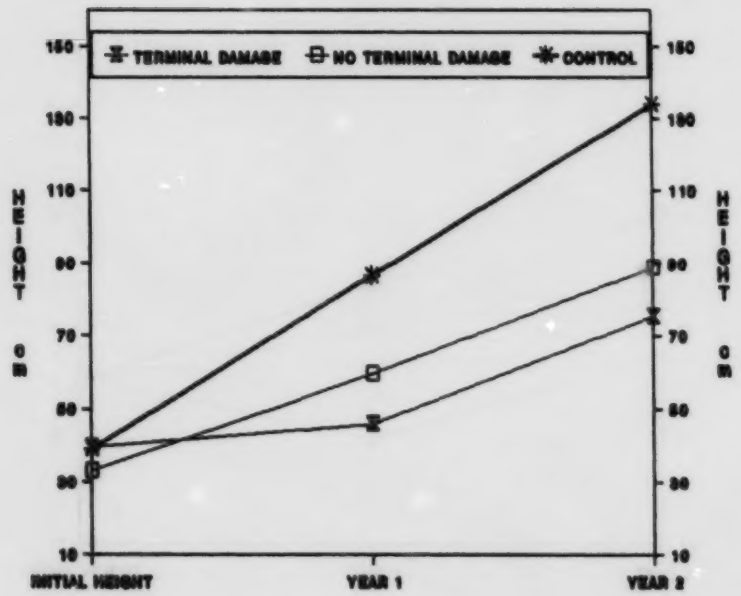

FIG. 13 GOLDEN FIR GROWTH - GREATER THAN 60% DEFOLIATION AT PLANTING

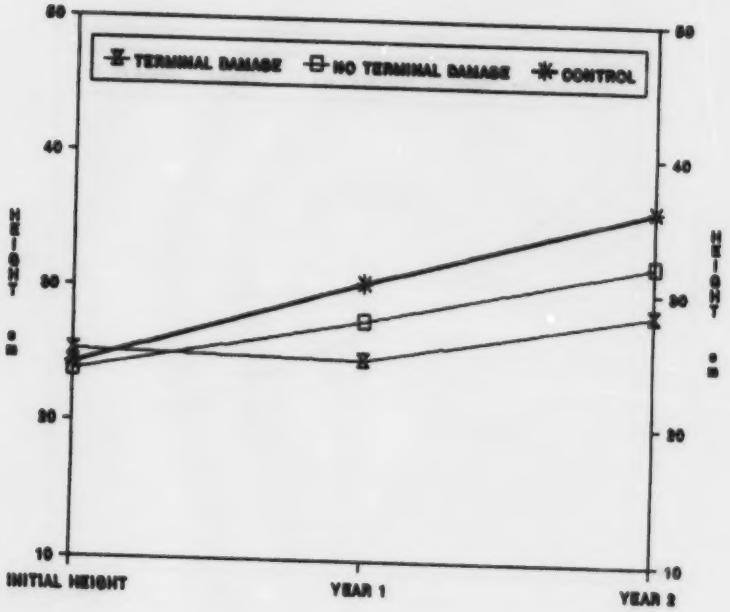

FIG. 14 GOLDEN FIR GROWTH - GREATER THAN 60% DEFOLIATION POST PLANTING

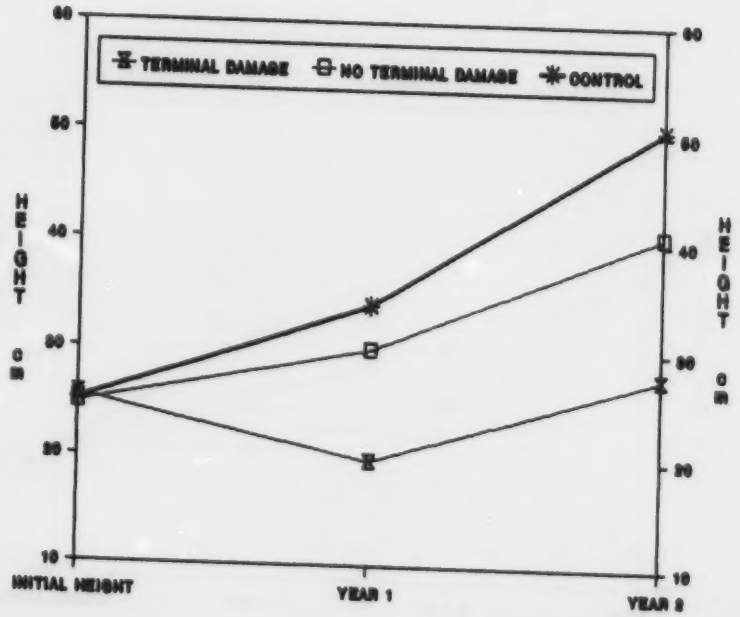

FIG. 15 INVERMERE FIR GROWTH-GREATER THAN 60% DEFOLIATION AT PLANTING

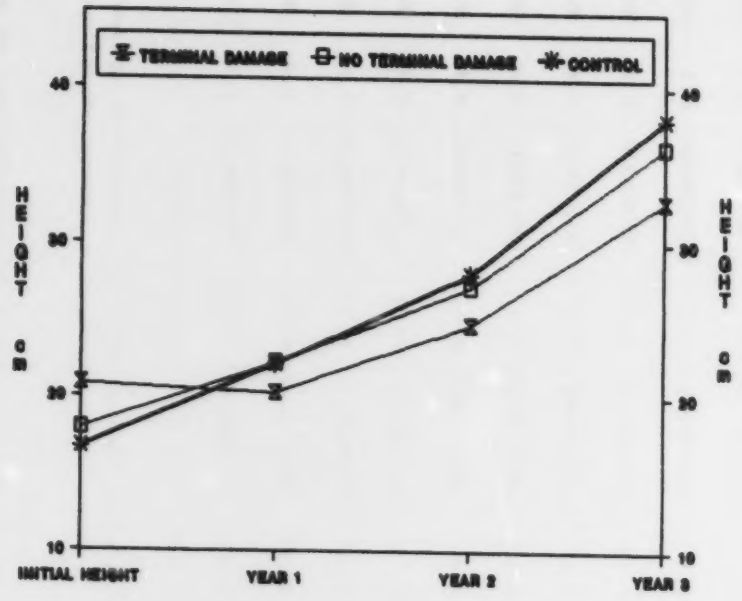

FIG. 16 INVERMERE SPRUCE GROWTH-GREATER THAN 60% DEFOLIATION AT PLANTING

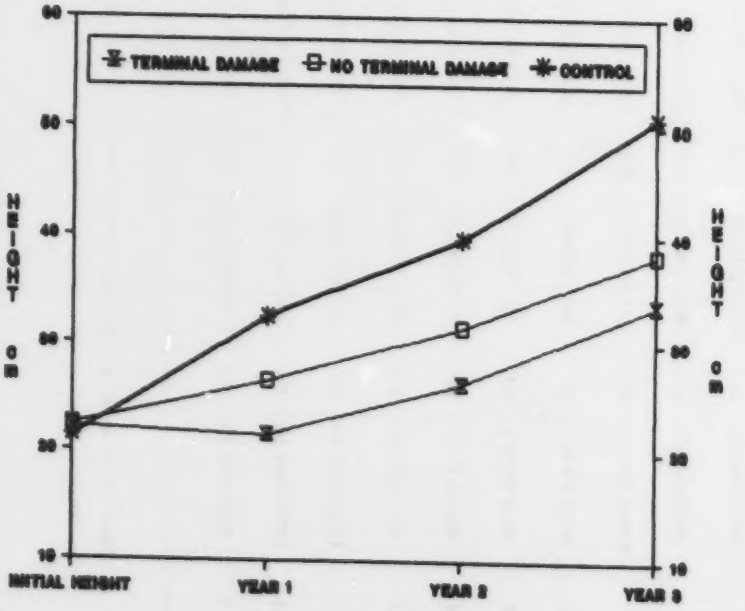

TABLE 9. SEEDLING DAMAGE INDEX - COMPARISON BETWEEN ALL LOCATIONS, SPECIES AND TIMING OF DEFOLIATION FOR DEFOLIATION GREATER THAN 60%.

PERCENT BAC MORTALITY		PERCENT BAC/PLANT MORTALITY		PERCENT TOTAL MORTALITY		PERCENT TERMINAL DAMAGE		PERCENT TOTAL GROWTH [1]		PRIMARY DAMAGE RATING [2]		SECONDARY DAMAGE RATING [3]	
GLDDFPOST	0.8	INVDFCUR	3.9	GLDPLPOST	6.9	GLDPLPOST	6	CLWPLCUR	+21	GLDPLPOST	5	CLWPLCUR	4
GLDPLPOST	1.6	GLDPLPOST	5.3	INVDFCUR	7.8	CLWPLCUR	12	INVDFCUR	22	CLWPLCUR	6	INVDFCUR	4
INVSPCUR	2.8	GLDLWCUR	6.5	CLWPLCUR	11.4	GLDPLCUR	21	GLDPLPOST	28	INVSPCUR	8	GLDPLPOST	4
CLWPLCUR	3.0	CLWPLCUR	8.4	INVPLCUR	12.7	INVPLCUR	33	GLDDFCUR	32	INVDFCUR	9	INVPLCUR	10
GLDPLCUR	3.0	INVPLCUR	8.4	GLDLWCUR	12.9	GLDLWCUR	52	INVSPCUR	33	GLDDFCUR	10	INVSPCUR	11
GLDDFCUR	3.9	INVSPCUR	11.8	INVSPCUR	14.6	GLDDFCUR	63	GLDLWPOST	38	GLDDFPOST	10	GLDLWCUR	13
INVDFCUR	3.9	GLDLWPOST	15.4	GLDDFPOST	21.9	GLDLWPOST	71	INVPLCUR	38	GLDPLCUR	14	GLDDFCUR	14
INVPLCUR	4.3	GLDDFPOST	21.1	GLDLWPOST	24.5	INVDFCUR	86	GLDLWCUR	42	INVPLCUR	14	GLDLWPOST	15
GLDLWCUR	6.4	GLDPLCUR	24.4	GLDPLCUR	27.2	INVSPCUR	93	GLDDFPOST	52	GLDLWCUR	15	GLDDFPOST	16
GLDLWPOST	9.1	GLDDFCUR	35.1	GLDDFCUR	39.0	GLDDFPOST	100	GLDPLCUR	58	GLDLWPOST	17	GLDPLCUR	19

1
Percentage difference in total height growth between control and defoliated trees after 2 years(except Golden larch current - 1 year).

2
Based on the addition of a numerical ranking(1 = lowest, 10 = highest) for direct BAC mortality and height growth in the second year.

3
Based on the addition of a numerical ranking(1 = lowest, 10 = highest) for total BAC mortality and height growth in the second year.

It is concluded that survival and height growth rates following BAC damage are related not only to the direct effects of the insect, but also to factors such as site, planting quality, the time of defoliation in relation to planting and possibly post-defoliation drought. Therefore, it appears impossible to conclusively state which species will incur the greatest losses during a BAC outbreak.

4.4 Vegetation Damage Correlation

As BAC larvae prefer herbaceous vegetation to most coniferous seedlings and appear to preferentially defoliate certain plants, the abundance and species of these alternate food sources play a considerable role in determing the damage levels sustained by seedlings during an outbreak. A third and major interacting factor is larval population density, because seedlings may sustain defoliation even though herbaceous vegetation is abundant when populations are large. A fourth factor is the stage of phenological development of the herbaceous plants in relation to larval instar development, because seedlings are more likely to be defoliated if larval emergence precedes the flushing and foliation of the herbaceous plants. Finally, the fifth complicating factor is that early defoliation retards the rate of phenological development, as the plants must re-form buds or expand adventitious or subcortical buds. It was impossible to analyze all of these various interactions in detail during the course of this study, but data were collected to provide some general observations on these interactions.

Previously, Hodgkinson(1986) reported that succulent species such as valerian(Valeria dioca), fireweed(Epilobium augustifolium), western meadowrue(Thalictrum occidentale) and Hooker's fairybells(Disporum hookeri) were preferred food sources for BAC larvae in the Prince George Forest Region. But in terms of providing an alternate food source to reduce seedling defoliation during an outbreak, the quantity of foliage of those species more preferred than seedlings becomes critical. Therefore, the data collected on percentage defoliation were multiplied by a factor representing the stage of the plant's phenological development, based on the rating system developed by Dierschke (1972) to obtain the ranking of species presented in Table 10 for the golden Forest District. Succulent perennial species which foliate early in the spring received the 6 highest rankings, followed by early-flushing woody shrubs such as serviceberry(Amelanchier alnifolia) and birch-leaved spirea(Spirea betulifolia). Vegetation such as sedge grass (Carex spp.) and gooseberry(Ribes spp.) were only defoliated when all other vegetation was completely defoliated, and defoliation was never observed on falsebox(Paxistima myrsinites).

TABLE 10. RANKING OF HERBACEOUS PLANT SPECIES BASED ON FEEDING PREFERENCE AND STAGE OF PHENOLOGICAL DEVLOPMENT.

COMMON NAME	SCIENTIFIC NAME	RANK
Western meadowrue	Thalictrum occidentale	1.0
Horsetail	Equisetum arvense	1.0
Fireweed	Epilobium augustifolium	2.0
Green false hellebore	Veratrum viride	3.0
Heart-leaved arnica	Arnica cordifolia	3.0
False Solomon's seal	Smilicina racemosa	5.0
Western larch	Larix occidentalis	5.5
Serviceberry	Amelanchier alnifolia	5.5
Rose	Rosa spp.	7.5
Birch-leaved spirea	Spirea betulifolia	8.0
Soapberry	Sheperdia canadiensis	8.0
Rocky Mountain maple	Acer glabrum	8.0
Trembling aspen	Populus tremuloides	10.0
Lodgepole pine	Pinus contorta	10.5
Western thimbleberry	Rubus parviflorus	10.5
Black twinberry	Lonicera involucrata	11.0
Utah honeysuckle	Lonicera utahensis	12.0
Willow	Salix spp.	12.0
Alder	Alnus spp.	13.0
Oceanspray	Holodiscus discolor	13.0
Dandelion	Taraxacum officinale	14.0
Snowberry	Symphoricarpus albus	14.0
Aster	Aster spp.	14.5
Tall Oregon-grape	Mahonia aquifolium	14.5
Pearly everlasting	Anaphalis margaritacea	15.0
Canadian bunchberry	Cornus canadiensis	15.5
Blueleaf strawberry	Fragaris virginiana	16.0
Western blue clematis	Clematis occidentalis	17.0
Sitka columbine	Aquilegia formosa	18.5
Great mullein	Verbascum thapsis	20.0
Violet	Viola spp.	20.0
White hawkweed	Hieracium albiflorum	21.0
Sedge grass	Carex spp.	21.5
Gooseberry	Ribes spp.	23.0
Falsebox	Paxistima myrsinites	23.0

In the Golden VD plots, it was observed that seedling defoliation was initiated on larch, but not on pine, even when abundant, preferred herbaceous vegetation was available, indicating that this conifer is highly palatable to BAC larvae(Table 10). Pine is less preferred, but still ranks in the middle of the preference list. Additionally, observations of larval feeding habits showed that the terminal buds of Douglas-fir were consumed before the older needles. During the initial Invermere data collection, it was also observed that defoliation occurred first on spruce, then pine and lastly on Douglas-fir when the species were planted in close proximity and subjected to equal larval populations.

The ultimate defoliation level of seedlings was analyzed in relation to the defoliation level of vegetation and to relatively high and low population densities of different larval instars. The preferred herbaceous species were defoliated quite early, and even at low population densities these species were close to 100% defoliation by the conclusion of the fourth instar. The average trends between level of vegetation defoliation at a given instar and final level of seedling defoliation are presented in Figs. 17-19. There was a high degree of variablity in the data so that prediction of ultimate seedling damage relative to vegetation defoliation on a site by site basis is difficult.

Larval instar stage can be readily identified by comparing the head capsule widths of larvae to the bar guide in Fig. 20(courtesy of L. Humble, Forestry Canada, 1989 unpub. data). Most feeding and defoliation of vegetation occurs during the fifth and sixth instars.

4.5 Pheromone Trapping Correlation

The pheromone trapping system employed in 1987 and 1988 used non-sticky traps and a two component pheromone, both of which are commercially available. In 1987, traps were placed in burned sites adjacent to known 1987 BAC infestations in the Clearwater and Golden Forest Districts. Both the Gibby and Ram wildfires in the Invermere Forest District were trapped in 1987, as there were no other recently burned sites available. Trapping is not normally done in the same blocks which have been defoliated, due to the dispersing role of the adult BAC moths. However, it was believed that because of the huge acreages encompassed by these burns that moths would re-infest the wildfires by ovipositing in adjacent areas, as only isolated portions of each burn had been defoliated in 1987.

The total catch per trap in 1987 ranged from 0 to 1667 and the mean trap catch was 692(Table 11). Moths were caught in all but one trap (which was continually damaged by an ungulate), indicating widespread dispersal of the moths. In 1988, BAC populations were observed in 13 of the 46(28%) trapping sites following early spring inspections. There were no larval populations large enough to cause defoliation of vegetation in the Ram burn and only extremely light populations were found in the Gibby burn; indicating that the moths caught in these traps were dispersing to other locations rather than re-infesting wildfires which were more than a year old. In contrast, in the early 1970's BAC moths re-infested the area of a wildfire and larval populations were present for 3 years. This occurred as a result of new, freshly burned sites

FIG. 17 COMPARISON OF SEEDLING VERSUS VEGETATION DEFOLIATION FOR LOW POPULATION LEVELS

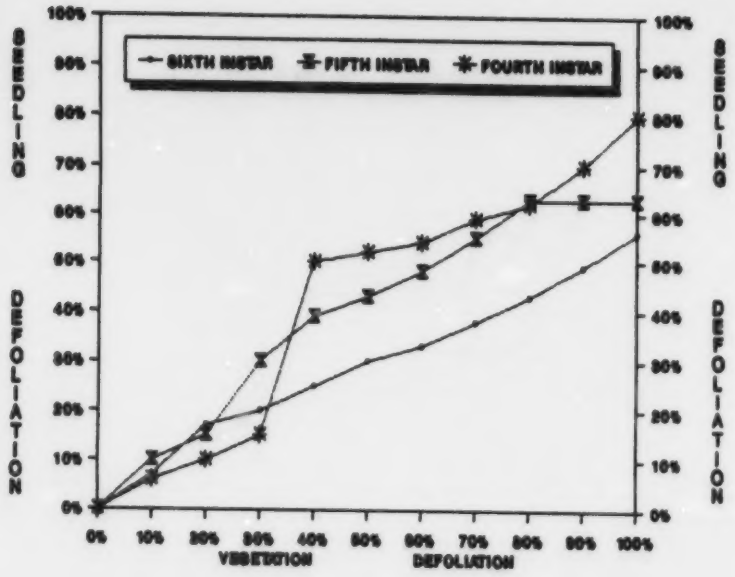

FIG. 18 COMPARISON OF SEEDLING VERSUS VEGETATION DEFOLIATION FOR HIGH POPULATION LEVELS

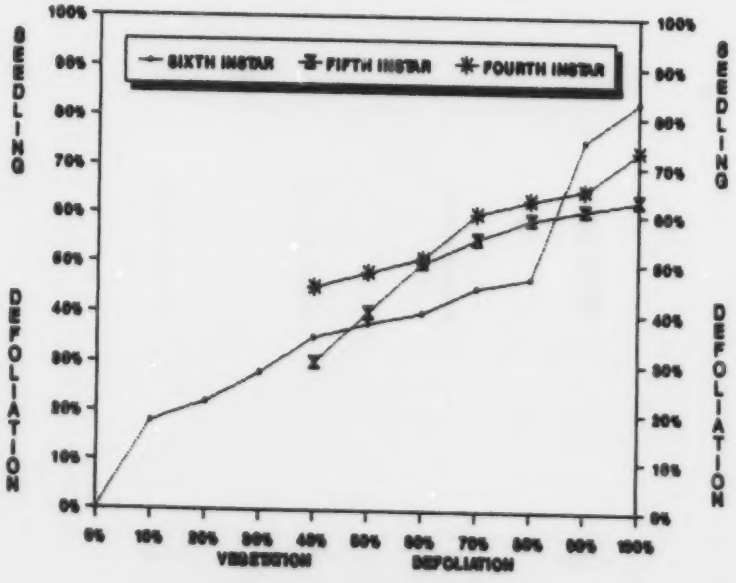

FIG. 19 COMPARISON OF SEEDLING VERSUS VEGETATION DEFOLIATION FOR ALL INSTARS

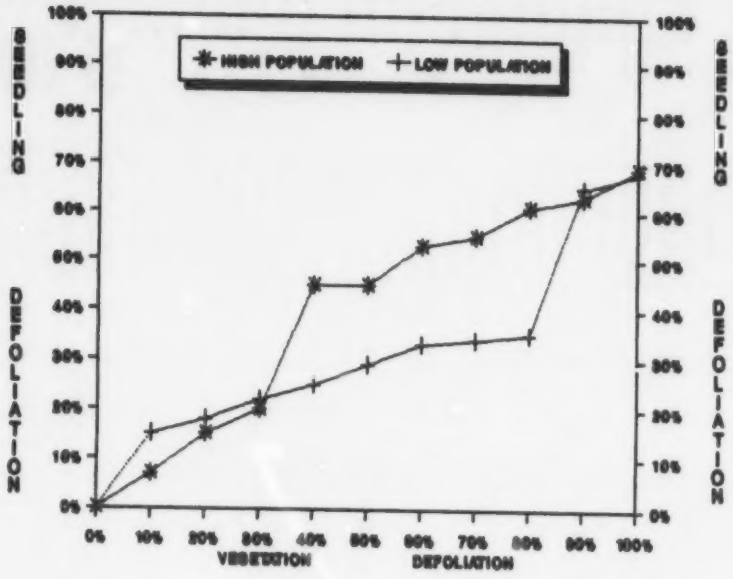

FIG. 20 BAR GUIDE FOR DETERMINATION OF BLACK ARMY CUTWORM LARVAL INSTARS

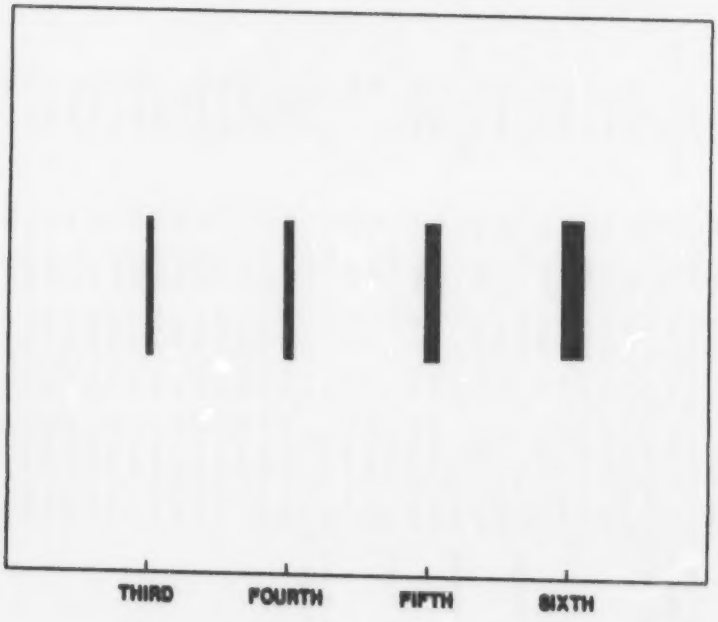

TABLE 11. SUMMARY OF SELECTED 1987 PHEROMONE TRAP CATCHES WITH SUBSEQUENT BAC LARVAL POPULATIONS AND LEVELS OF SEEDLING DAMAGE.

TRAPPING LOCATION	FOREST DISTRICT	AGENCY[1]	TRAP NO.	PROXIMITY[2]	NO. BAC MOTHS	1988 POP'N LEVEL	REMARKS
C.P. 21/26	Golden	FC	GD-7	4	1667	Large	Mod/severe seedling defol. in 1988
C.P. 21/26	Golden	FC	GD-5	4	1438	Large	Mod/severe seedling defol. in 1988
C.P. 21/26	Golden	FC	GD-6	4	1282	Large	Mod/severe seedling defol. in 1988
C.P. 21/26	Golden	FC	GD-8	4	1248	Large	Mod/severe seedling defol. in 1988
C.P.25	Golden	FC	GD-4	1	1181	Moderate	Mod. seedling defoliation in 1988
Gibby wildfire	Invermere	FC	IV-6	4	1157	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-24	8	1115	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-3	4	1073	None	No BAC pop'ns observed
C.P. 23	Golden	FC	GD-1	3	1002	Light	Light seedling defoliation in 1988
Gibby wildfire	Invermere	FC	IV-14	1	949	Ex. light	Light def. of veg., no seedling damage
C.P. 25	Golden	FC	GD-2	3	939	Light	Moderate seedling defoliation in 1988
Gibby wildfire	Invermere	FC	IV-8	5	860	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-11	5	843	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-25	7	839	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-10	5	817	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-12	5	790	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-15	1	776	Ex. light	Light defol of veg, no seedling damage
Gibby wildfire	Invermere	FC	IV-5	4	772	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-16	3	748	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-2	2	636	Ex. light	Light defol of veg, no seedling damage
Ram wildfire	Invermere	FC	IV-23	9	608	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-26	6	571	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-13	1	571	Ex. light	Light defol of veg, no seedling damage
Ram wildfire	Invermere	FC	IV-28	5	532	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-29	4	463	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-7	1	449	Ex. light	Light defol of veg, no seedling damage
C.P. 23	Golden	FC	GD-3	2	391	Light	Light seedling defoliation in 1988
Gibby wildfire	Invermere	FC	IV-9	5	279	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-21	2	245	None	No BAC pop'ns observed
Opening No. 3007	Clearwater	FC	CW-3	2	225	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-18	1	198	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-19	3	176	None	No BAC pop'ns observed
Opening No. 3007	Clearwater	FC	CW-4	2	171	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-22	10	154	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-27	6	153	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-17	1	144	None	No BAC pop'ns observed
Opening No. 6006	Clearwater	FC	CW-1	3	135	None	No BAC pop'ns observed
Opening No. 6006	Clearwater	FC	CW-2	3	118	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-30	2	85	None	No BAC pop'ns observed
Opening No. 8528	Clearwater	FC	CW-6	1	83	None	No BAC pop'ns observed
Opening No. 8528	Clearwater	FC	CW-7	1	65	None	No BAC pop'ns observed
Opening No. 8528	Clearwater	FC	CW-8	1	63	None	No BAC pop'ns observed
Gibby wildfire	Invermere	FC	IV-1	2	56	None	No BAC pop'ns observed
Opening No. 8528	Clearwater	FC	CW-5	1	55	None	No BAC pop'ns observed
Ram wildfire	Invermere	FC	IV-20	2	0	None	No BAC pop'ns observed

[1] Indicates the funding agency for trapping was Forestry Canada(FC) or the B.C. Forest Service(BCFS).

[2] Indicates relative proximity to a known 1987 BAC infestation within the Forest District.

becoming available each year within the original wildfire as a result of salvage logging operations. No populations were observed in 1988 throughout the Clearwater F.D., although low levels of moths were caught. But there were substantial populations observed in the Golden Forest District, with the degree of seedling damage being related to the number of moths captured(Table 11).

Based on these positive results, the trapping program was expanded in 1988 to include the districts of Revelstoke and McBride. As in 1987, moths were caught in all of the traps, and the catches ranged from 1 to 1161 and the mean catch was 227 moths(Table 12). Inspections of all sites trapped in 1988 was conducted in early May 1989 and BAC populations were observed in 43% of the trapping sites. However, in only one site near Golden was the population large enough to cause seedling damage.

Pheromone trap numbers give an indication of the presence or absence of a BAC population in the fall, but many factors affect that population between the time of trapping and larval emergence the following spring. Low trap numbers indicate areas where there is no risk of seedling damage and plans can be made to plant the site. High trap catches only indicate the potential for damage and further checks should be made in the spring to determine if the population has successfully overwintered and whether an avoidance program should be initiated.

The mean trap catch dropped dramatically from 692 in 1987 to 227 in 1988, which may indicate that if all potential oviposition sites are trapped, a major difference in the average catch between two years may signal the rapid decline of the population in the following year. This hypothesis needs to be confirmed by future research.

Based on the results obtained in this study, the following preliminary levels of moth catches are proposed to indicate relative risk, but more experience in trapping correlations is necessary to verify these levels.

less than 350 moths	no defoliation of vegetation or seedlings is expected
between 350-600 moths	defoliation of vegetation is common with occasional seedling damage
greater than 600 moths	high risk of vegetation and seedling defoliation, follow-up assessment is recommended the following spring

In both 1987 and 1988, subsamples of the pheromone traps were emptied every two weeks to determine the duration of the flight period (Table 13). During 1987, flight was delayed in the Invermere Forest District relative to Golden and Clearwater. This was expected as the temperatures would be lower and insect development slower at higher elevations. Similarly, the initiation and completion of the flight period in Golden was much earlier in the warmer temperatures of 1987 as compared to the cooler temperatures of 1988.

TABLE 12. SUMMARY OF SELECTED 1988 PHEROMONE TRAP CATCHES WITH SUBSEQUENT BAC LARVAL POPULATIONS AND LEVELS OF SEEDLING DAMAGE

TRAPPING LOCATION	FOREST DISTRICT	AGENCY [1]	TRAP NO.	PROXIMITY [2]	NO. BAC MOTH	1989 POP'N LEVEL	REMARKS
McKALE CREEK BRIDGE	McBride	FC	MB-27	3	1161	Light	Mod. defol. of veg., no seedling damage
McKALE CREEK BRIDGE	McBride	FC	MB-24	3	1123	Light	Mod. defol. of veg., no seedling damage
McKALE CREEK BRIDGE	McBride	FC	MB-25	3	1096	Light	Mod. defol. of veg., no seedling damage
McKALE CREEK BRIDGE	McBride	FC	MB-26	3	1035	Light	Mod. defol. of veg., no seedling damage
19 KM. MOUNTAIN VIEW ROAD	McBride	FC	MB-1	2	1069	Light	Light defol. of veg., no seedling damage
19 KM. MOUNTAIN VIEW ROAD	McBride	FC	MB-3	2	1037	Light	Light defol. of veg., no seedling damage
19 KM. MOUNTAIN VIEW ROAD	McBride	FC	MB-2	2	986	Light	Light defol. of veg., no seedling damage
19 KM. MOUNTAIN VIEW ROAD	McBride	FC	MB-4	2	961	Light	Light defol. of veg., no seedling damage
EAST TWIN CREEK	McBride	FC	MB-5	1	713	Light	Mod. defol. of veg., no seedling damage
DONALD CURVE - TCHWY.	Golden	FC	GD-20	3	661	Moderate	Light to moderate seedling damage
BACHELOR CREEK -115 KM.	Golden	FC	GD-40	5	532	None	No BAC pop'ns observed
ICE RIVER - BEAVERFOOT	Golden	BCFS	GD-49	4	488	None	No BAC pop'ns observed
90 KM. WEST COLUMBIA F.S.R.	Golden	FC	GD-38	4	486	Light	Mod. defol. of veg., no seedling damage
FRED LAING RIDGE-TFL 23	Revelstoke	FC	RS-33	3	458	None	No BAC pop'ns observed
BACHELOR CREEK - 107 KM.	Golden	FC	GD-46	5	441	None	No BAC pop'ns observed
EAST TWIN CREEK	McBride	FC	MB-6	1	439	Light	Mod. defol. of veg., no seedling damage
BACHELOR CREEK-110 KM.	Golden	FC	GD-43	5	437	None	No BAC pop'ns observed
CHATTER CREEK-OPENING #59	Golden	FC	GD-23	4	434	Light	No BAC pop'ns observed
FRED LAING RIDGE-TFL 23	Revelstoke	FC	RS-32	3	421	None	No BAC pop'ns observed
19 KM. MOUNTAIN VIEW ROAD	McBride	FC	MB-8	1	416	Light	Light defol. of veg., no seedling damage
CHATTER CREEK-OPENING #59	Golden	FC	GD-25	4	415	Light	No BAC pop'ns observed
BACHELOR CREEK-110 KM	Golden	FC	GD-42	5	411	None	No BAC pop'ns observed
CHATTER CREEK-OPENING #59	Golden	FC	GD-24	4	397	Light	Light defol. of veg., no seedling damage
BACHELOR CREEK-110 KM	Golden	FC	GD-41	5	379	None	No BAC pop'ns observed
40 KM. BEAVERFOOT F.S.R.	Golden	FC	GD-8	3	378	Light	Light defol. of veg., no seedling damage
94 KM. WEST COLUMBIA F.S.R.	Golden	FC	GD-39	4	378	Light	Light defol. of veg., no seedling damage
EAST TWIN CREEK	McBride	FC	MB-7	1	374	Light	Mod. defol. of veg., no seedling damage
CHATTER CREEK-OPENING #59	Golden	FC	GD-26	4	373	None	No BAC pop'ns observed
SUICIDE MTN.-115 KM BUSH FSR	Golden	FC	GD-27	5	366	None	No BAC pop'ns observed
ICE RIVER - BEAVERFOOT	Golden	BCFS	GD-47	4	360	None	No BAC pop'ns observed
PALLISER STATION	Golden	FC	GD-11	1	336	None	No BAC pop'ns observed
ESPLANADE BAY	Golden	BCFS	GD-59	1	298	None	No BAC pop'ns observed
ICE RIVER - BEAVERFOOT	Golden	BCFS	GD-48	4	280	None	No BAC pop'ns observed
ESPLANADE BAY	Golden	BCFS	GD-60	1	275	None	No BAC pop'ns observed
PALLISER STATION	Golden	FC	GD-13	1	260	None	No BAC pop'ns observed
WARSAW ROAD	Revelstoke	FC	RS-22	1	246	None	No BAC pop'ns observed
ABETIBIE LAKE	Golden	BCFS	GD-50	1	159	None	No BAC pop'ns observed
ESPLANADE BAY	Golden	FC	GD-29	1	158	None	No BAC pop'ns observed
ABETIBIE LAKE	Golden	FC	GD-16	1	156	None	No BAC pop'ns observed
ICE RIVER - BEAVERFOOT	Golden	BCFS	GD-51	3	154	None	No BAC pop'ns observed
45 KM. BEAVERFOOT F.S.R.	Golden	FC	GD-9	2	149	None	No BAC pop'ns observed
PALLISER STATION	Golden	FC	GD-10	1	144	None	No BAC pop'ns observed
RED ROAD	Golden	FC	GD-30	2	100	None	No BAC pop'ns observed
BUSH ARM-95 KM BUSH F.S.R.	Golden	FC	GD-28	3	89	None	No BAC pop'ns observed
ALBERT CANYON - TCHWY.	Revelstoke	BCFS	RS-1	9	26	None	No BAC pop'ns observed
DUTCHMAN CREEK	Revelstoke	BCFS	RS-20	2	12	None	No BAC pop'ns observed

[1] Indicates the funding agency for trapping was Forestry Canada(FC) or the B.C. Forest Service (BCFS).

[2] Indicates relative proximity to a known 1988 BAC infestation within the Forest District.

TABLE 13. SUMMARY OF 1987 AND 1988 BI-WEEKLY PHEROMONE TRAP CATCHES.[1]

LOCATION	YEAR	15-31 JULY	1-15 AUG	16-31 AUG	1-15 SEPT	16-31 SEPT
Clearwater	1987	30%	29%	29%	11%	1%
Invermere	1987	5%	42%	44%	8%	1%
Golden	1987	35%	30%	26%	8%	1%
Golden	1988	6%	20%	38%	31%	5%
Revelstoke	1988	3%	26%	33%	29%	9%

[1] Percentages of total trap catch within the trapping district.

5.0 SUMMARY

Mortality was generally lower than expected. Seedlings had to be at least 60% defoliated before mortality increased significantly above the levels in the control seedlings. Most mortality was associated with 100% defoliation combined with terminal bud destruction. The majority of mortality occurred within one year of defoliation, but this could not be determined until the following spring; as many seedlings appeared dead immediately following defoliation, but subsequently re-flushed and continued growing. Because severe defoliation reduces root growth, any additional stress factor which is increased after defoliation appears to cause a rapid increase in the level of mortality. These factors include: planting coincidentally with larval feeding, improper planting in rotten wood, J-roots and post-defoliation drought. Mortality was also higher when defoliation occurred on dry, excessively well-drained sites and where there was a poor match of the seedling species to the site.

There were no significant differences mortality levels between controls and well-planted seedlings defoliated by the BAC, or between sites and species experiencing similar levels of damage. But when BAC defoliation was combined with poor planting or post-defoliation drought, significant differences in mortality occurred. Severely defoliated larch incurred the highest levels of mortality directly due to BAC defoliation, regardless of the time of defoliation in relation to planting. Within the other species, mortality from BAC defoliation only was lower when defoliation occurred 1 year after planting.

Total mortality was extemely variable between species, location and time of defoliation, indicating the pronounced influence of extraneous stress factors when combined with BAC defoliation upon seedling survival rates.

Height growth loss was most pronounced in the year of defoliation if the terminal bud was destroyed and planting was coincident with defoliation. In this case, growth losses were prolonged and differences in growth rates between damaged and undamaged seedlings were still diverging 2 and 3 years later. Pine and larch were more affected by terminal damage than Douglas-fir or spruce.

Based on defoliation level and stage of phenological develpoment, early-flushing species were ranked as most important in providing alternate food sources for BAC larvae. Larch seedlings were defoliated even when abundant vegetation was still available, indicating that this seedling species is highly palatable to BAC larvae. Comparisons of vegetation defoliation at various instar stages to the level of final seedling damage was extemely variable, even between adjacent plots within an infestation.

Pheromone trap catches indicated relative levels of subsequent larval populations the following spring, but further research is required to verify this predictive warning system.

6.0 FIELD IMPLICATIONS AND CONCLUSIONS

The well-known catastrophic losses due to a BAC infestation reported by Ross and Ilnytzky(1977) and significant re-planting costs in the Sue fire near Golden served to identify that foresters need to be concerned about and aware of regeneration pests. However, the losses and costs reported were based on 'expected' mortality, not actual data; and the costs of replanting due to BAC were lower than the costs due to replanting from 'other causes'. This not meant to imply that serious losses due to the BAC are not a reality, but rather to illustrate that a given insect or disease must cause documented and economically significant losses to be regarded as a 'pest' within the classical definition of the word.

As the mortality attributed directly to the BAC on well-planted trees never exceeded 9% after 3 growing seasons for seedlings with greater than 60% defoliation during this study, the level of risk regarding losses of entire plantations is probably lower than previously believed. However, the mortality due to the combined effects of poor planting and BAC defoliation was substantially larger than the mortality directly attributed to BAC only, therefore indicating the importance of planting quality and other stress factors in determining post-defoliation survival rates. The highest total mortality levels of 39% recorded in this study would generally not result in the requirement for complete replanting of infested blocks. However, the patchy distribution of BAC populations within a cutblock may result in concentrated centres of mortality and therefore inadequate levels of stocking within these discrete areas, which may need to be fill-in planted to achieve minimum stocking standards.

Obviously, much higher levels of overall mortality have occurred during BAC outbreaks than those reported from this study(Maher 1988, Ross and Ilnytzky 1977), and will probably occur in the future when populations within a cutblock are very high, the level of available preferred vegetation is not sufficient to meet the feeding demands of the larvae, planting quality is poor, and post-defoliation drought occurs.

During the collection of damage appraisal data, it was frequently observed that severely defoliated and damaged seedlings which appeared to be dead immediately following the outbreak reflushed and were alive 6-8 weeks later. A portion of these seedlings succumbed during the first winter, but the actual levels of mortality recorded were significantly lower than what would have been expected had a survival survey been done immediately after the defoliation. Therefore it is strongly recommended that any surveys to determine survival of plantations which have experienced BAC defoliation not be undertaken for 1 year so that an accurate measure of mortality is obtained.

After 3 years, the mean difference in height between control and severely defoliated seedlings ranged from 13-22%(mean 18%) in the Invermere data bases, and from 8 - 40%(mean 21%) in the Golden data bases after 2 years. However, growth still had not recovered to the rates of the controls, consequently it is still unknown if these differences will affect the length of time required to reach the free-growing state. Therefore, remeasurements of the permanent damage appraisal plots should be undertaken in the future.

The correlations of vegetation versus seedling defoliation presented will vary from one geographical area to the next, depending on the species and quantity of herbaceous vegetation present. Based on the experience gained through the course of this study, it appears highly unlikely that an adequate guideline to estimate potential seedling defoliation at the onset of an outbreak could be developed; due to the extreme variability in correlations between these factors at various locations within an infestation.

Outbreaks have only been recorded in the following biogeoclimatic zones: Engelmann Spruce-Subalpine Fir, Interior Cedar Hemolock and the Sub-boreal Spruce. Within these zones, newly-burned sites are susceptible to BAC infestations. A pheromone trapping system is currently being tested to detect where these infestations may occur and to provide an indication of site hazard. This will enable the total number of burned sites to be reduced down to a very few which will need to be checked for larval populations prior to planting.

Delaying planting a few weeks until feeding has been completed is the easiest and least expensive option on moist sites. Allowing planting to proceed, surveying for mortality levels the following year and replacing killed seedlings is a viable option when reasonable levels of preferred vegetation are present. Postponement of planting until the following year may be chosen if the site is subject to drought and vegetative competition is not a important factor. Expensive insecticide treatments($295/ha, courtesy of L. Pittman, Evans Forest Products Ltd., 1988 unpub. data) are effective in killing the larvae, but they are generally completed too late to prevent much damage to the seedlings.

Such treatments are difficult to schedule in order to accomplish the objective of foliage protection, as the decision to initiate a treatment(based on population size and available alternate vegetation) probably could not be made until the fourth instar. By the time the operations are actually underway a substantial portion of the seedling defoliation is likely to have already occurred. And due to the dispersing nature of the BAC, no protection is gained in subsequent years, as the population has moved to new locations.

Therefore, the following series of guidelines should be considered for implementation in the three susceptible biogeoclimatic subzones:

1. Identification(on an annual basis) of all susceptible sites which have been burned in the past 12 months.

2. Pheromone trapping from 1 July to 30 Sept. on susceptible sites to identify high population levels.

3. All sites with high trap catches should be examined in early spring to estimate densities of larval populations and levels of preferred alternate vegetation available.

4. In assessing the need for an avoidance program when BAC is present, one would need to consider the size and stage of development of the larval population, the amount of preferred vegetation that is available as an alternate food source, the amount of vegetative competition and the site charactersitics such as soil moisture etc.

5. When the risk of damage is high, the following options(ranked in order of decreasing preference) are suggested:

   a. Postponement of planting until after pupation has started.

   b. Proceed with planting and complete a survival survey the following year, re-planting as required.

   c. Delay planting for one year.

   d. Application of an insecticide treatment.

In conclusion, the results from this study indicate that the losses to BAC were lower than expected. It appears that in most cases these losses could be easily minimized by understanding the consequences of BAC defoliation in relation to seedling mortality and height growth reductions; and by having a management strategy in place prior to the occurrence of BAC populations.

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APPENDIX 1

DAMAGE APPRAISAL PLOT DESCRIPTIONS.

LOCATION SPECIES TIMING	BIOGEO-CLIMATIC SUBZONE	ELEVATION	YEAR INITIATED	LOCATION DESCRIPTION
CLWPLCUR	ICHmw3	900	1987	Seedling species well matched to site. Moderate herbaceous competition. Plentiful available soil moisture after defoliation. Moderate nutrient status.
IMVPLCUR	ESSFdc1	1400	1987	Seedling species poorly matched to site, with moderate to severe grass competition. Plentiful available soil moisture after defoliation. Low nutient status.
IMVDFCUR	ESSFdc1	1400	1987	Same as above.
IMVSPCUR	ESSFdc1	1400	1987	Same as above.
GLDPLCUR	ICHmk1	1150	1988	Seedling species poorly matched to site in an experimental planting in large BAC population with low levels of herbaceous competition. Deficit levels of available soil moisture after defoliation. Moderate nutrient status.
GLDPLPOST	ICHmk1	1050	1988	Seedling species well matched to site, with moderate to severe herbaceous competition. Deficit levels of available soil moisture after defoliation. High nutrients.
GLDDFCUR	ICHmk1	1050	1988	Seedling species poorly matched to site, with moderate herbaceous competition. Deficit levels of available soil moisture after defoliation. Moderate nutrient status.
GLDDFPOST	ICHmk1	1050	1988	Same as above.
GLDLHCUR	ICHmk1	1200	1989	Seedling species well matched to site in an experimental planting to obtain damage appraisal data. Plentiful available soil moisture after defoliation. Light to moderate herbaceous competition. Moderate nutrient status.
GLDLHPOST	ICHmk1	1050	1988	Seedling species well matched to site, with moderate to severe herbaceous competition. Deficit levels of available soil moisture after defoliation. High nutrient status.

APPENDIX 2